Marshall

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

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REPLY TO ATTN OF: GP

TO: KSI/Scientific & Technical Information Division
Attn: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code KSI, the attached NASA-owned U.S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No.	: 3,851,238
Government or Corporate Employee	: McDonnell Douglas Corp. Huntington Beach, CA
Supplementary Corporate Source (if applicable)	:
NASA Patent Case No.	: MFS-22,073-1

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:

YES [X] NO [ ]

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of column No. 1 of the Specification, following the words "...with respect to an invention of ..."

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Enclosure

MFS-22,073-1

United States Patent [19]

Fletcher et al.

[11] **3,851,238**

[45] **Nov. 26, 1974**

[54] **PHASE-LOCKED SERVO SYSTEM**

[76] Inventors: **James C. Fletcher**, Administrator of the National Aeronautics and Space Administration with respect to an invention by; **Clifford Burdin**, Omaha, Nebr.

[22] Filed: **Oct. 26, 1973**

[21] Appl. No.: **409,991**

[52] **U.S. Cl.** **318/649,** 318/608, 318/640, 318/675

[51] **Int. Cl.** **H02p 5/46**

[58] **Field of Search** 318/648, 649, 640, 608, 318/618, 675

[56] **References Cited**

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Primary Examiner—B. Dobeck
Attorney, Agent, or Firm—Wayland H. Riggins; L. D. Wofford, Jr.; John R. Manning

[57] **ABSTRACT**

A phase lock servo system for synchronizing the rotation of a slip ring assembly with the rotation of an air bearing table so that a minimum of torque will be imparted through cables extending from the slip ring assembly to the air bearing table as such is rotated. The system includes two servo loops. The first servo loop includes a rate gyroscope carried on the air bearing table which generates a signal through a summing junction to be compared with a signal coming from a tachometer coupled to the slip ring assembly. The corrective signal is applied to a torque motor for rotating the slip ring assembly. The second servo loop includes a pair of photo detector cells which generate pulses responsive to the rotation of the air bearing table and slip ring assembly which are fed through a phase detector, and a variable gain amplifier to the summing junction circuit to provide a fine adjustment for rotating the slip ring assembly.

6 Claims, 3 Drawing Figures

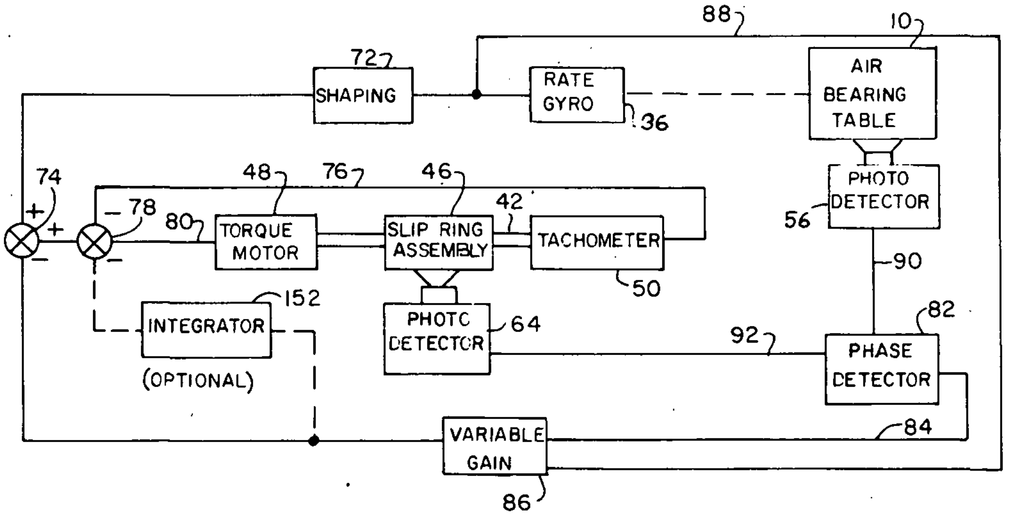
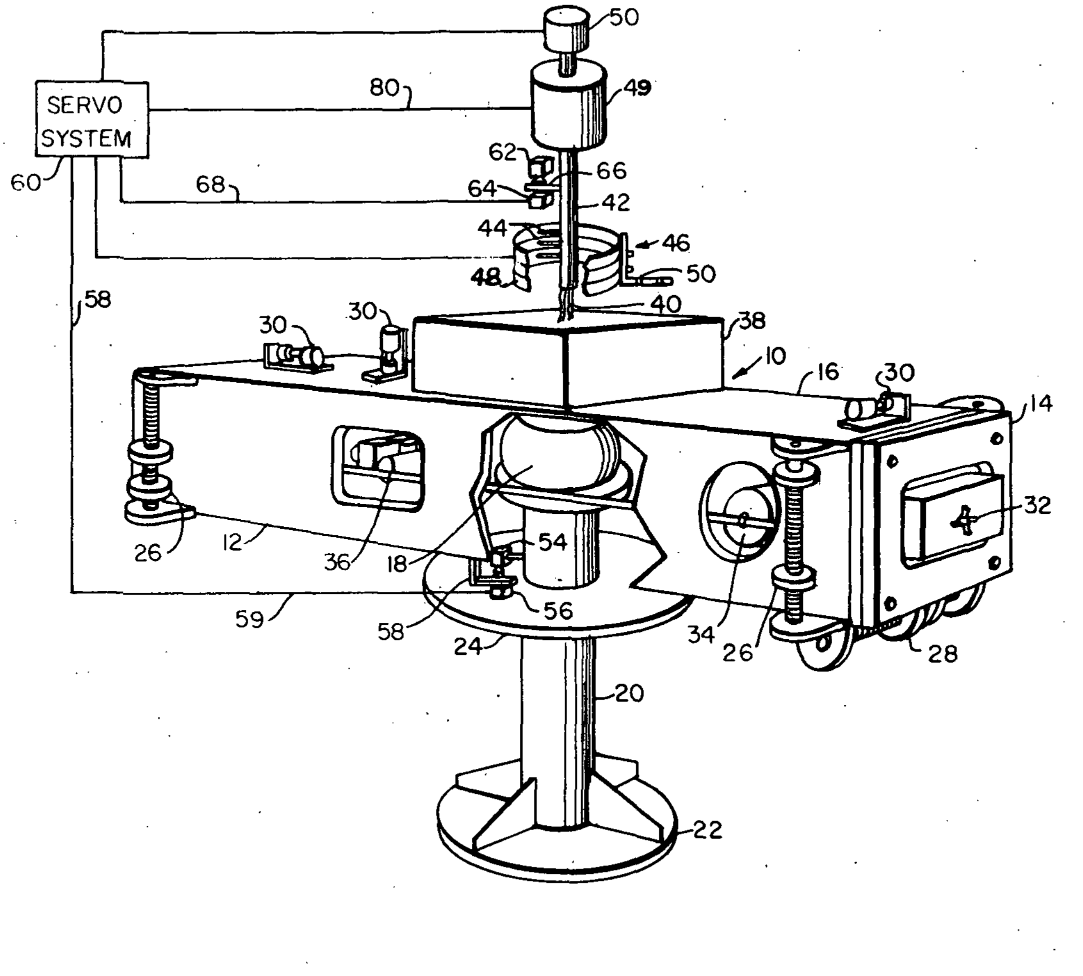


Fig. 1.


SERVO SYSTEM
50
49
80
60
62
66
64
42
68
44
46
50
48
58
40
30
30
38
10
16
30
14
32
26
12
36
18
54
58
56
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24
34
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28
20
22

Fig. 2.

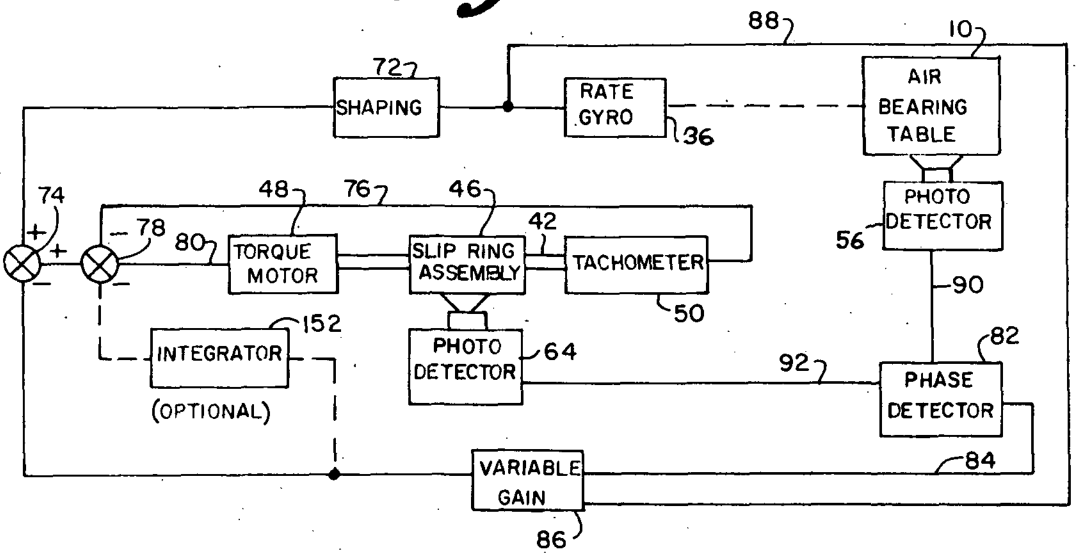
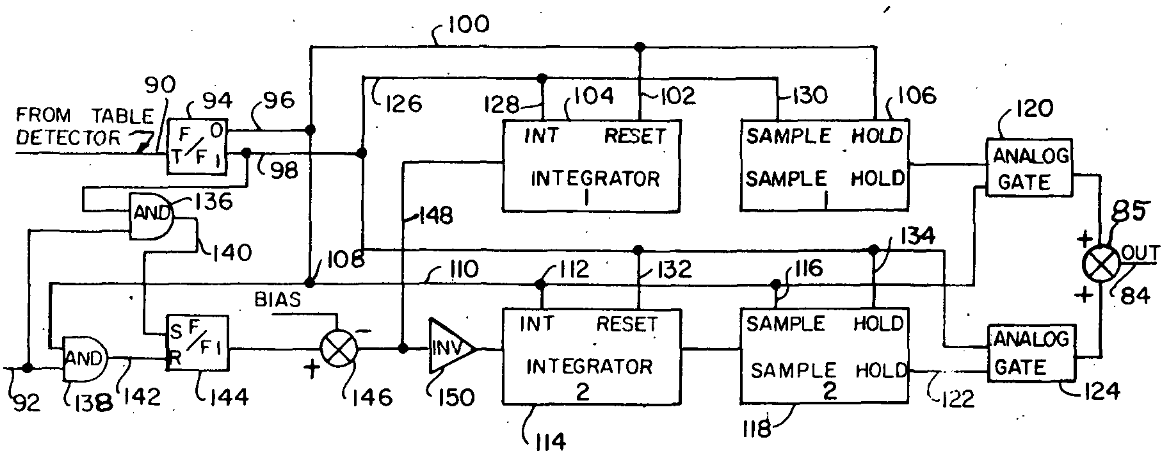

88
10
72
SHAPING
RATE GYRO
36
AIR BEARING TABLE
74
48
76
46
PHOTO DETECTOR
78
80
42
56
TORQUE MOTOR
SLIP RING ASSEMBLY
TACHOMETER
90
50
152
INTEGRATOR
PHOTO DETECTOR
64
82
92
(OPTIONAL)
PHASE DETECTOR
VARIABLE GAIN
84
86

Fig. 3.


100
90
94
96
126
128
104
102
130
106
120
FROM TABLE DETECTOR
F O
T F I
98
INT RESET
INTEGRATOR 1
SAMPLE HOLD
SAMPLE HOLD 1
ANALOG GATE
AND
136
148
85
140
108
110
112
132
116
134
OUT
84
BIAS
INT RESET
INTEGRATOR 2
SAMPLE HOLD
SAMPLE HOLD 2
ANALOG GATE
AND
S F
R F I
INV
92
138
142
144
146
150
114
118
122
124

PHASE-LOCKED SERVO SYSTEM

ORIGIN OF THE INVENTION

The invention described herein was made in the performance of work under a NASA Contract, and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85–568 (72 Stat. 435; 42 U.S.C. 2457).

BACKGROUND OF THE INVENTION

This invention relates to a phase lock servo system, and more particularly to a phase lock servo system which includes two servo loops, one for making a coarse adjustment and the other for producing a fine adjustment for synchronizing the rotation of a slip ring assembly with an air bearing table.

Heretofore, the slaving of one rotating body to another has usually been accomplished by utilizing a mechanical means for measuring the rotation of the master system and generating a signal to control the slave system so that such is rotated at the same rate. These systems are not practical for use in extremely sensitive situations, such as when it is desired to simulate zero gravity conditions.

In order to simulate outer space conditions for testing, various components, such as small rocket engines, gyroscope sensors, etc., a table mounted on air bearings is utilized. When the rockets being tested are fired such causes the table to rotate. If conventional wiring were used to supply energy to the components on the table, the torque produced by the wires twisting would interfere with the tests. While the wires can be coupled to the table through various slip ring assemblies, which includes brushes, such is still not completely satisfactory due to the frictional contact between the brushes and the slip ring assembly.

SUMMARY OF THE INVENTION

The invention provides a system for accurately synchronizing a slip ring assembly with an air bearing table so that wires can extend from the slip ring assembly to the air bearing table for supplying power to components carried thereon, without imparting torque to the table. The system includes a rate gyroscope which is carried on the air bearing table for generating an electrical signal indicative of the rotation of the table. The signal from the rate gyro circuit is fed to a summing junction circuit to be compared with a signal being produced by a tachometer coupled to the slip ring assembly. The summing junction circuit produces a corrective signal which is fed to a torque motor for rotating the slip ring assembly substantially at the same rate that the air bearing table is rotated. In order to more accurately synchronize the rotation of the slip ring assembly with the air bearing table, a phase lock servo system is utilized in conjunction with the normal servo system. The phase locked servo system includes a pair of photo detectors which produce pulses responsive to the rotation of the air bearing table and the slip ring assembly. The pulses from these photo detectors are fed into a phase detector which generates an analog signal indicative of the phase difference between the two pulses. This analog signal is fed through a variable gain amplifier to the summing junction circuit for providing a more accurate corrective signal to the torque motor. The output from the rate gyroscope is also fed to the variable gain amplifier to vary the gain of the amplifier.

Accordingly, it is an important object of the present invention to provide a servo system which is extremely accurate.

Another important object of the present invention is to add a phase locked servo loop to a conventional servo loop being utilized for synchronizing one rotating member with another so as to produce accurate slaving therebetween.

Still another important object of the present invention is to provide a system for supplying electrical power to a rotating member without imparting torque thereto.

These and other objects and advantages of the invention will become apparent upon reference to the following specification, attendant claims and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view, with parts broken away, for purposes of clarity and parts shown diagramatically of an air bearing table being supplied with power from a slip ring assembly,

FIG. 2 is a block diagram of a servo system utilized for synchronizing the rotation of a slip ring assembly with an air bearing table, and

FIG. 3 is a detailed block diagram of a phase locked servo system utilized in the system of FIG. 2.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring in more detail to FIG. 1 of the drawings, there is illustrated an air bearing table, generally designated by the reference character **10** which has side walls **12** joined by end walls **14** and a top **16.** The table is supported on a conventional air bearing assembly **18** carried on top of an upright stand **20.** The stand has an enlarged circular base portion **22** and a circular platform **24** spaced upwardly therefrom. The table is adapted to accommodate adjustable weights **26** and **28** which are used for balancing the table. Fine weight adjustments **30** are carried on top of the table. The details of the table will not be described, since such is conventional and the invention can be used in connection with supplying power to any type of rotating element.

Positioned in and on the table are various components that are to be tested, such as reaction jets **32** carried on the end wall **14,** and a gas supply **34** for the reaction jets suitably mounted on the inside thereof. A rate gyroscope **36** is mounted by any suitable means within the table so as to sense the rotation of the table. A rectangular shaped housing **38** is carried on top of the table **10** for housing various components. This rate gyroscope supplies signals over some of the wires **40** extending upwardly therefrom through a tubular shaft **42** to brushes **44** forming part of a slip ring assembly, generally designated by the reference character **46.** Outer rings **78** of the slip ring assembly are shown schematically as being fixed to a bracket which can be suitably attached to any support member. Electrical signals and power pass through the outer rings **48,** the brushes **44,** the wires **40** to the various components of the air bearing table **10.** Electrical power and signals can be taken from and supplied to the outer rings **48** of the slip ring assembly by any suitable conductors (not shown).

In order to prevent unwanted torque from being imparted to the table **10** through the wires **40**, it is necessary to rotate the wires, which are carried in the shaft **42**, at the exact speed that the table is rotating. If the table were permitted to rotate at a different speed from the wires **40**, they would twist and impart torque thereto, interferring with the simulation of outer space conditions.

Therefore, the shaft **42** of the slip ring assembly **46**, is driven by a torque motor **49**. Positioned on the same shaft **42** extending through the torque motor **49** is an electrical tachometer **50**, which generates a signal indicative of the rate of rotation of the shaft **42**.

Additional sensing devices are provided for sensing the rotation of the shaft **42** and the air bearing table **10** so as to produce a more accurate corrective signal. Mounted on the column **20** is a light source **54** which has spaced therefrom a photo-detector **56**. An L-shaped bracket **58** is carried by the table **10** for interrupting this light source each time the table rotates thereby. When the light source **54** is interrupted a pulse is generated by the photo-detector cell **56** and fed over line **59** to a servo system **60**. A similar photo detector is provided for sensing the rotation of the shaft **42** and includes a light source **62** spaced from a photo detector **64**. A pulse is produced by the photo-detector **64** each time an outwardly extending arm **66** carried by the rotating shaft **42** interrupts the light beam. These pulses are fed over lead **68** to the servo system. The light source **62** and the photo-detector **64** can be mounted on any suitable bracket (not shown).

Referring in more detail to FIG. **2**, there is illustrated a block diagram which includes the elements of the servo system **60**. As previously mentioned, a rate gyroscope **36** is carried on the air bearing table **10** and generates a signal indicative of the rotation of the air bearing table **10**. This signal is fed through a shaping circuit **72** to a summing junction circuit **74**. The summing junction circuit **74** is an operational amplifier. The tachometer **50** carried on shaft **42** generates a signal which is fed over lead **76** indicating the rate of rotation of the shaft **42**. This signal is fed to summing junction circuit **74**. The signal being supplied to the summing junction circuit **74** from the rate gyroscope **36** is compared with the signal being supplied from the tachometer **50** and fed to a summing junction **78** to generate a corrective signal on lead **80** that causes the torque motor **49** to rotate the shaft **42** at substantially the same rate of rotation as the air bearing table **10** rotates. This helps to prevent the wires **40** leading from the brushes **44** of the slip ring assembly from twisting and imparting torque to the air bearing table. One problem encountered with the loop previously described, is that it is not sufficiently accurate to prevent some torque from being applied from the slip ring assembly to the air bearing table. To more accurately synchronize the roation of the air bearing table **10** with the slip ring assembly, a second servo loop is provided.

The second servo loop includes the photo-detector **56** which generates a pulse each time the table makes one revolution and the beam from light-source **54** is interrupted by the bracket **58**. This pulse is fed into a phase detector **82**. A similar pulse is generated by photo-detector **64** each time the arm **66** interrupts the light beam from the light source **62** because of rotation of shaft **42** of the slip ring assembly. The pulse from photo-detector **64** is also supplied to the phase-detector **82**, and a corrective analog signal is produced on lead **84** indicating the phase relation of the two pulses. This analog signal is fed through a variable gain amplifier **86** to the summing junction **74** to produce a voltage which is applied to the torque motor **48**. The rotation of the shaft **42** is thus brought into proper phase with the rotation of the air bearing table.

The output of the phase-detector **82** is proportional to the phase relation of pulses from photo-detectors **56** and **64**. The gain of the phase-detector **82** is inversly proportional to repetition rate of the pulses. In order to maintain constant gain in the loop, variable gain amplifier **86** is used.

The output of the rate gyro **36** is coupled by means of lead **88** to the variable gain amplifier **86** so that the gain of the variable gain amplifier is directly proportional to the pulse rate and the loop gain therefore is not affected by the speed that the air bearing table **10** is rotating.

Referring now to FIG. **3** of the drawings, there is illustrated a detailed block diagram of the phase-detector circuit **82**. The circuit includes an input lead **90** coming from the photo-detector **56**, and an input lead **92** coming from the photo-detector cell **64**. The input lead **90** is fed into a trigger flip-flop **94**, which has two outputs **96** and **98**, respectively. The output **96** is coupled by means of a lead **100** to a reset input **102** of an integrator **104**. It is, also, coupled to a hold input of a sample hold circuit **106**. Output lead **96** extends to junction **108** which is coupled by lead **110** to an integrate input **112** of an integrator **114**. It is, also, coupled to a sample input **116** of a sample hold circuit **118**. The output of the sample hold circuit **106** is connected to one input of an analog AND gate **120**, which has its output connected to lead **84** through summing junction **85**. Lead **84** is connected to the variable gain amplifier **86**. The output of sample hold circuit **118** is connected to an input **122** of another analog AND gate **124** which has its output coupled to output lead **84** through summing junction **85**.

The other output **98** of flip-flop **94** is coupled by lead **126** to an integrate input **128** of the integrator **104**. It is, also, coupled to the sample input **130** of the sample hold circuit **106**. The reset input **132** of the integrator **114** and the hold input **134** of the sample hold circuit **118** are also coupled to the output lead **98** of the flip-flop **94**. It is noted that the input lead of analog gate **120** is coupled to lead **110** for receiving a signal from the "zero" output labeled **96** of flip-flop **94**. The other input of analog gate **124** is coupled to the "one" output labeled **98** of flip-flop **94**.

An AND gate **136** has one input connected to output lead **98** of flip-flop **94** and the other input lead connected to input lead **92** for receiving a signal from the photo-detector **64**. An AND GATE **138** has one input coupled to lead **92**, and the other lead connected to output lead **96** of flip-flop **94**. Outputs **140** and **142**, respectively, of AND gates **136** and **138** are coupled to an input of a set-reset flip-flop **144**. The "one" output of flip-flop **144** is fed to a summing junction circuit **146**. The summing junction circuit has a minus **2.5** volt bias coupled thereto. The output of the summing junction **146** is connected by lead **148** to an input of integrator **104** to be integrated thereby. It is, also, coupled through an inverter **150** to an input of integrator **114** to be integrated thereby when such is activated.

In order to aid in understanding the operation of the phase lock loop circuit illustrated in FIG. **3**, assume first that flip-flop **94** and **144** are in the "zero" state. Assume, also, that the rate gyro loop is perfect. These assumptions are made merely to simplify operation explanation. Proper operation of the circuit is not dependent on the validity of these assumptions. If the table is given a constant angular velocity the slip ring assembly follows at the same velocity as air bearing table because of the signal generated by the tachometer being fed back to the summing junction circuit **78** to be compared with the signal from the rate gyro.

If the first pulse generated by the photo-detector **64** associated with the slip ring assembly occurs just momentarily, after the pulse generated by the photo-detector **56**, then flip-flop **94** and flip-flop **144** go to the "one" state. When flip-flop **94** is in the "one" state an output is provided on output lead **98**, and is fed to the integrate input **128** of the integrator **104**, and the sample input of the sample hold circuit **106**. It is, also, fed to the reset input **132** of integrator **114** and the hold input **134** of the sample hold circuit **118**. The pulse from photo detector **64** passes through AND gate **136** since there is an input on lead **98**. This pulse sets flip-flop **144** producing a plus **5** volt signal on its "one" output. This 5 volt signal is summed with a minus 2.5 bias at the summing junction circuit **146**, producing a plus 2.5 voltage. This voltage is applied over lead **148** to the integrator **104** to begin integration. Integrator **104** integrates the input signal until the second pulse from the table detector changes flip-flop **94** from the "one" state to the "zero" state. At this time, the sample hold circuit **106** holds the voltage that the integrator had reached. This voltage is applied to an input of analog AND gate **120** which receives a signal from flip-flop **94** when such is in the "zero" state. The AND gate **120** thus allows an analog corrective signal to be applied to the output lead **84**. The amplitude of this analog signal is proportional to the phase difference between the pulse produced by the photo-detector **64** associated with the slip ring and the pulse produced by the photo-detector associated with the air bearing table, the amplitude being zero when phase difference is 90°.

When flip-flop **94** is changed from the "one" state to the "zero" state by the second pulse being fed to the phase-detector from the photo-detector cell **56** a signal is applied to the integrator input **112** of integrator **114**, and to the sample input **116** of the sample hold circuit **118**. The second pulse coming from photo-detector **64**, which lags the second pulse from photo-detector cell **56**, causes the flip-flop **144** to be triggered off. Therefore, there is a zero voltage at the "one" output of flip-flop **144**. Since there is a minus **2.5** bias voltage being applied to the summing junction circuit **146**, there is minus 2.5 voltage applied to the inverter **150** which inverts such and feeds it to the input of integrator **114**. Integrator **114** integrates this signal and the sample hold circuit **118** samples the output of integrator **114**. The integrator **114** continues integrating until the next pulses is applied to the flip-flop **94** which causes the sample-hold circuit to hold the voltage of the integrator **114** and the integrator **114** to be reset. The voltage being held by the sample hold circuit **118** is applied through the analog gate **124** to the output lead **84** and on to the summing junction circuit **78**. This signal on output lead **84** causes a bucking voltage to be applied to the torque motor **49** to reduce the velocity of the slip ring assembly. Because the slip ring assembly **46** begins rotating slower than the table after the first and second pulses, the third pulse from the photo-cell **64** associated with the slip ring assembly lags behind the third pulse from photo-cell **56** associated with the table. The output of the sample hold circuit **106** is now less and velocity of shaft **42** increases although, still less than that of the speed of rotation of the table **10**. When the output of flip-flop **144** lags the output of flip-flop **94** by **90** electrical degrees, the output of the integrator **104** is "zero" and the shaft **42** of the slip ring assembly **46** and the table **10** rotate the same velocity and are positioned at 180 angular degrees to each other.

Of course, the assumption of a perfect rate gyro loop is not valid. Any errors of scale fact and linearity match between rate gyroscope **36** and the tachometer **50** and the rate loop servo errors result in a phase relation between the rotation of the table **10** and the shaft **42** of the slip ring assembly being other than 180°. If this is objectionable, an optional integrator **152** can be coupled into the circuit of FIG. **2** between the summing junction **78** and the output of the variable gain amplifier **86**. The purpose of utilizing the two sets of integrators and sample hold circuits, as shown in FIG. **3**, is to produce a smooth operation and a constant voltage on the output lead **84** when correction is required, since one set of integrator and sample hold circuits is used during one-half of the cycle, and the other set is utilized during the other half of the cycle.

The primary purpose of AND gates **136** and **138** are to prevent corrections of more than 180 angular degrees, which could be caused by initial phasing of flip-flop **94** and flip-flop **144** or by a loss of a pulse.

While a preferred embodiment of the invention has been described using specific terms, such description is for illustrative purposes only, and it is to be understood that changes and variations may be made without departing from the spirit or scope of the following claims.

What is claimed is:

1. A system for synchronizing the rotation of a pair of rotating bodies comprising:

a. a first rotating member,

b. a second rotatable member,

c. a rate gyroscope carried by said first rotating member generating a first electrical signal indicative of the rate of rotation of said first rotating member,

d. a torque motor coupled to said second rotatable member for rotating said second rotatable member,

e. means coupled to said second rotatable member for generating a second electrical signal indicative of the rate of rotation of said second rotatable member,

f. a voltage producing means provided for receiving said first and second electrical signals and feeding a corrected voltage to said torque motor causing said torque motor to rotate said second rotabable member at substantially the same rate of rotation as said first rotating member,

g. a first photo detection means for generating a pulse each time said first rotating member rotates past a reference point,

h. a second photo detection means for generating a pulse each time said second rotatable member rotates past a reference point,

i. a phase detector means coupled to said first and second photo detection means generating an analog signal corresponding to the phase difference between said pulses from said first and second photo detection means, and

j. means for coupling said analog signal to said voltage producing means for varying said corrective signal so as to more accurately synchronize the rotation of said second rotatable member with said first rotating member.

2. The system as set forth in claim **1** wherein,

a. said rotating member is an air bearing table, and

b. said second rotatable member is a slip ring assembly.

3. The system as set forth in claim **2** wherein said slip ring assembly includes:

a. a plurality of stacked rings,

b. a rotatable shaft coupled to said torque motor,

c. electrical brushes carried by said rotatable shaft engaging said stacked rings, and

d. electrical conductors extending from said brushes to said air bearing table for providing electrical paths from said slip ring assembly to said air bearing table.

4. The system as set forth in claim **1** further comprising:

a. a variable gain amplifier coupled between said phase detector means and said voltage producing means for amplifying said analog signal being fed to said voltage producing means.

5. The system as set forth in claim **4** further comprising:

a. means for coupling said first electrical signal from said rate gyroscope to said variable gain amplifier for providing a reference voltage for said variable gain amplifier.

6. The system as set forth in claim **1** wherein:

a. said means coupled to said second rotatable member for generating a second electrical signal is a tachometer.

* * * * *